

GHGT-10

## Development of Risk Assessment Tool for CO<sub>2</sub> Geological Storage

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### Abstract

In this paper, the authors review state of the arts of risk assessment about CO<sub>2</sub> geological storage. Then, the authors introduce our risk assessment tool under development, which aims to assist decision-making for safety and risk management legislations around CO<sub>2</sub> geological storage by way of optimum level of risk quantification. It is expected that our tool will contribute for evaluation of CO<sub>2</sub> injection, especially to shallower aquifers. The authors show example calculations of surface propagation of 0.1 to 10<sup>-3</sup> % of CO<sub>2</sub> release from 1-million ton/year injection. Calculated results are evaluated comparing with known CO<sub>2</sub> impact value. The most results of example air propagation analysis prove risks are negligible level. Exceptions are some special geometry like craters. We are thinking it is important to present rational reasons to distinguish issues whether to be negligible or not. The authors are expecting to accomplish the first prototype of our tool by the end of this fiscal year.

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*Keywords:* CO<sub>2</sub> geological storage, risk analysis and management, fractures, faults, migration of CO<sub>2</sub>, impact;

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### 1. Introduction

Various contexts of risks have been discussed in relation with time sequence of CO<sub>2</sub> geological storage: site selection, injecting operation, closing well and stewardship, quantitative estimation of CO<sub>2</sub> emission reduction, consistency of CO<sub>2</sub> cap, public perception, local hazard, environment, health and safety issue of area, system safety, geo-technical safety, long-term reliability, communication with society, economical profit and certainty of investment. These considerations involve increasing needs of risk quantification. Demands of quantification arise from three major areas:

- First comes from discussion about inclusion of CO<sub>2</sub> geological storage within CDM (Clean development mechanism) scheme<sup>1, 2</sup>. For calculation of CO<sub>2</sub> reduction effects, it needs estimation of any little potential CO<sub>2</sub> leakage risks transportation and inject operation of CO<sub>2</sub>.

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- Second comes from necessity of developing guidelines and/or legislation for environmental and safety protection of CO<sub>2</sub> injection projects. Some countries, including Japan, have just published safety and environmental protection guidelines for large sized experimental CO<sub>2</sub> geological storage project<sup>3,4</sup>. Those documents present areas that have to be considered risks. Nevertheless, when considers safety management legislation for business-sized projects, further efforts of data accumulation and analysis shall be required to establish concrete assessment basis.
- Third demand of risk assessment comes from individual site selection, operational planning and management. Geological formations differ site by site. Accumulation of experiences and data of this kind of new technology are still limited in the world.

In this paper, we will discuss areas of risk considerations of CO<sub>2</sub> geological storage, and will refer to increasing needs of quantitative risk assessment. Then introduce our risk assessment tool under development. It evaluates CO<sub>2</sub> migration in relation with fractures or faults within stratus and estimates impact of seepage to surface. The first prototype tool is expected to complete by the end of this fiscal year.

## 2. Consideration of Risk Assessment of CO<sub>2</sub> Geological Storage

	Phase			
	Site selection	Injection	Closure	Post-Closure
Geological factor	Long-term, Short-term Stability, Geo-chemical process			
Operation	Safety of high pressure gas plant, chemical plant Peripheral impact, external impact Mitigation factor			Monitoring
Safety				
Local/regional	Property of injected CO <sub>2</sub>			
Environment	Long-term and Short-term CO <sub>2</sub> migration			
Social aspect	Legislation (Environment, safety, energy)			

Table 1. Range of risk considerations and phases of operation<sup>5</sup>.

There are various considerations of risks in relation with time sequence of CO<sub>2</sub> geological storage: site selection, injecting operation, closing well and stewardship (Table 1). To evaluate those risks, the most essential issue is quantitative estimation of CO<sub>2</sub> fixation and/or leakage within geo-formations from point of technological view. Safety, environmental and economical issues directly connect with migration of CO<sub>2</sub> and surface facilities for transportation and injection. Without such estimations, none of us can decide whether specific risk is negligible or not, and will not able to distinguish impacts and rational mitigation measures.

Considerations of risks within CO<sub>2</sub> geological storage shall be categorized into three (Figure 1)<sup>6</sup>:

### A. Area of specific consideration

- Screening risk assessment for site selection
- Site assessment for assessing environmental impact
- Detailed risk assessment for planning, start, operation and closing

### B. Purpose of the assessment

- Site selection (PA)
- Environmental impact (SA)
- Safety & risk management (HSE)

- Economical assessment (RBA)
- C. Endpoint of evaluation
- Impact on human
  - Ecological impact
  - Impact on geological environment
  - Impact on natural resources

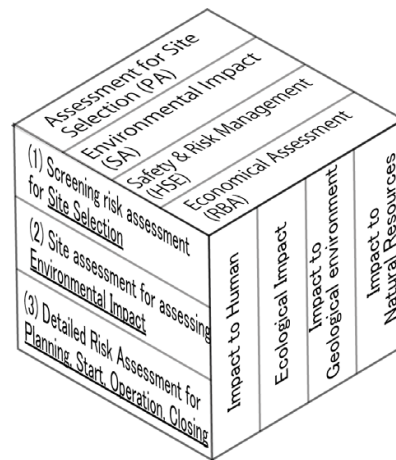


Figure 1. Structure of risk assessment considerations<sup>7</sup>.

### 3. Issues around Risk Quantification

In the meantime, there are three categories of risk quantification, quantification of probability of hazards in other words:

- Prior probabilities (ex. probability of appearances of spots of dice. Probability theory is applicable.)
- Statistical probabilities (ex. average life expectancy, incident rate. Statistics data are required for calculation. )
- Presumed probabilities (ex. when probability theory or statistics are not available. Presumptions like Delphi method, Monte Carlo simulation are applicable.)

Concerning to operations relate with CO<sub>2</sub> geological storage, we don't have enough general statistics. Therefore, we have to settle presumed probabilities depend on need. There are apprehensions about overly quantized risk assessments; those will not suite reality:

- Quantitative risk assessment is integration of forecasts and statistics with different level of accuracies.
- Some assessments may neglect non-quantifiable or inaccessible information which difficult to forecast.

To assist rational decision-making, we have to pay sufficient attention to maintain reasonable level of quantification, i.e.: evaluation of potential seepage including possibility, uncertainty, flow rate, and duration.

### 4. Development of Risk Assessment Tool

Our risk assessment tool is aiming to evaluate risks those relate with safety and risk management of above B category. As regard with risk evaluation for safety and risk management, numerical estimation of potential

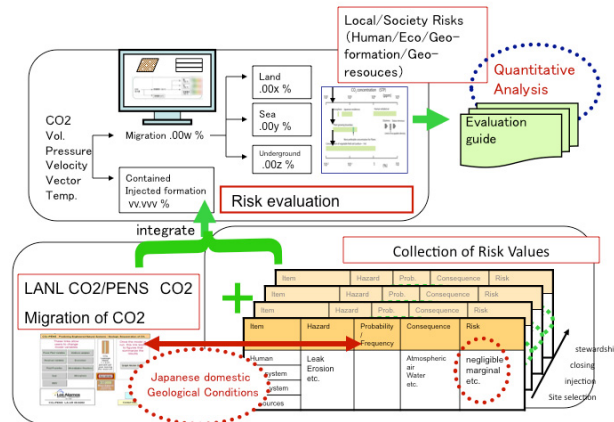


Figure 2. Concept of risk assessment tool.

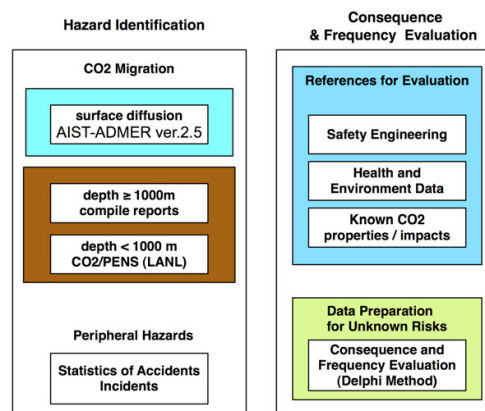


Figure 3 Element and data for risk evaluation.

probability and quantity of CO<sub>2</sub> leakage is key of any risk value decisions.

To offer optimum decision basis for safety and risk management of CO<sub>2</sub> geological storage, our risk assessment tool is consisted from hazard identification part, which is consisted from CO<sub>2</sub> migration evaluation part (both underground and surface, peripheral hazard) and consequence and frequency evaluation part (Figure 2, Figure 3)<sup>8</sup>.

For hazard impact estimation, we utilize preliminary hazard analysis (PHA) methodology. Using PHA format, the authors are collecting hazard elements and gathering information that will be able to be utilized for semi-quantification of probability or frequency and consequences, especially hazard which have potential impact onto surface. (Figure 4)

CO<sub>2</sub> injected target depth varies from deeper than -2000 [m] level of gas or oil seams to shallower than -800 [m] level of coal seams or aquifers. Aquifers are being regarded as to be promising injection target<sup>9</sup>. In shallower than -800 [m] aquifers, storage capacity of CO<sub>2</sub> will be smaller compared to deeper formations as the matter of pressure balance between rock and injected CO<sub>2</sub>. Even though, we can storage CO<sub>2</sub> into aquifers.

One of essential parts of risk assessment of CO<sub>2</sub> geological storage is evaluation of fractures or faults: whether they will act as seals against fluids or paths of fluid?

As regard with fractures or faults deeper than -1500 [m] level, Færseth proposed a scheme to judge sealing possibility<sup>10</sup>. Takahashi reported that cracks in tested semimetal rocks will tightly close and never pass fluid when applied 25 [MPa] (equivalent to about -1000 [m] depth rock pressure), based on experimental study<sup>11</sup>.

As for faults in shallower than -1000 [m] level in Japan, some reports analyzed qualitative relationship between depth of faults and seal functions, using gas outburst statics in coal seams in Japan (Figure 5)<sup>12</sup>. They summarized following tendencies:

- Namely, 50 % of gas outburst related with faults of 1 - 650 [m] elevation difference. (In other words, 50 % of observed faults had acted as seal for coal gases.)
- When broke through smaller faults, coal gases came without fail. (In other word, smaller faults act as seals.)
- When broke through larger faults, coal gases came in half cases. (In other word, half of larger faults acted as seals.)
- It was observed that tendency of proportional relationship between depth of faults and frequency of gas outburst accidents.

These are qualitative analysis about relationship between shallower faults depth and sealing capacity. Nevertheless, it is difficult to find reports that derive quantitative relationship between faults depth and sealing capacity of shallower stratus. Therefore, we are conducting literature survey and trying numerical analysis over shallower fractures and faults.

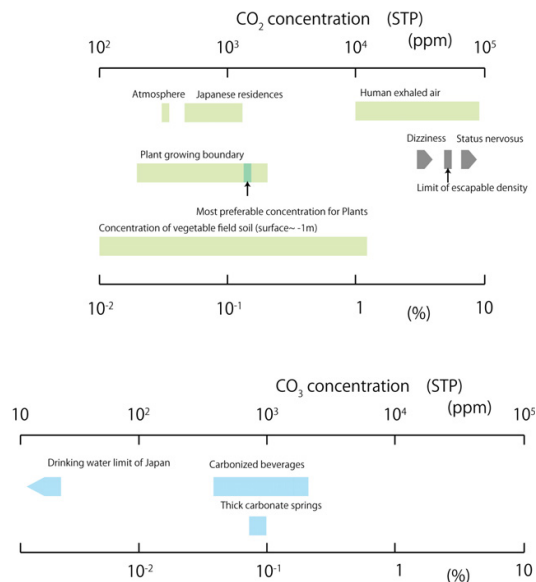


Figure 4. Example of data for impact evaluation.

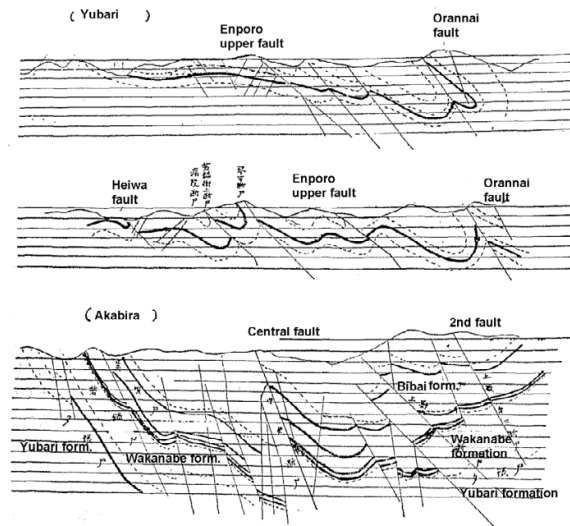


Figure 5. Fault distribution in Ishikari coalfield in Hokkaido, Japan.

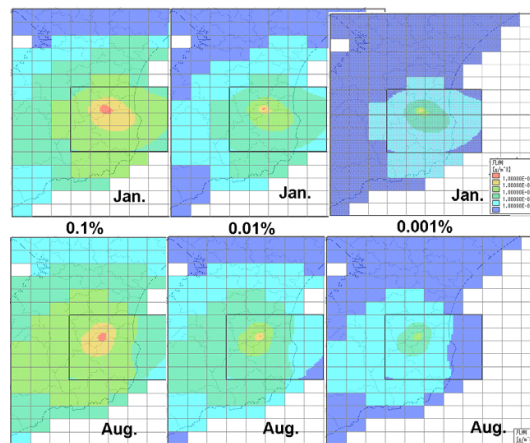


Figure 6. Calculation example of surface propagation of CO<sub>2</sub> seepage. Seepage rates are 10<sup>-1</sup> %, 10<sup>-2</sup> % and 10<sup>-3</sup> % to 1x10<sup>6</sup> ton/year injection. Wind and temperature conditions are January and August of 2009 in Japan. In this calculation, only diffusion of gas molecule is considered. CO<sub>2</sub> dissolution into water is not considered. Comparing this result with Figure 4, even 10<sup>-3</sup> % seepage from 1x10<sup>6</sup> ton/year injection is not preferable. (Used AIST ADMER ver.2.5)

Concerning to numerical simulation of CO<sub>2</sub> migration in underground via fractures and faults, we are utilizing model strata data into CO2/PENS, which was developed by LANL<sup>13</sup> with MOU agreement. Details of simulation of CO<sub>2</sub> migration in underground, Sakamoto presents in his paper in GHGT10.

We are also designing function of impact calculation of surface area, including estimation of air propagation caused by little seepages using numerical simulation tool for ambient pollution analysis, AIST-ADMER ver.2.5<sup>14</sup>.

Figure 6 shows examples of calculation result of surface propagation of CO<sub>2</sub> seepage. In this case, seepage rates are 10<sup>-1</sup> %, 10<sup>-2</sup> % and 10<sup>-3</sup> % from 1x10<sup>6</sup> ton/year injection rate. Wind and temperature conditions are taken from local climate data of January and August of 2009 from Japan meteorological observatory. In this calculation, only diffusion of gas molecule is considered. CO<sub>2</sub> dissolution into water is not considered.

Calculation results show, 10<sup>-1</sup> % seepage from 1x10<sup>6</sup> ton/year injection will produce more than 10<sup>-4</sup> g/m<sup>3</sup> of CO<sub>2</sub> concentration (about 0.05 ppm) in adjacent ambient air, and 10<sup>-3</sup> % seepage from the same injection rate will result less than 10<sup>-4</sup> g/m<sup>3</sup> of CO<sub>2</sub> in adjacent ambient. Compare Figure 6 calculation results with surface CO<sub>2</sub> impact of Figure 4, there seems none of potential impact.

Nevertheless, when calculate special geometry like craters, the same rate seepage produce rather dense CO<sub>2</sub> ambient within crater.

These results of the calculation will be utilized for not only risk evaluation but injection site selection. It is expected that the most result of the air propagation analysis will prove there are negligible level of risks, except for some special geometries. Nevertheless, we are thinking it is important to present rational reasons for distinguish issues whether negligible or have to keep in mind.

We are expecting to publish the first prototype of our tool by the end of this fiscal year.

## 5. Conclusion

In this paper, we categorized aspects of risk considerations of CO<sub>2</sub> geological storage, and reviewed increasing needs of quantitative risk assessment. Then we introduced development of risk assessment tool. We are developing risk assessment tool that consisted from hazard impact estimation part, CO<sub>2</sub> migration evaluation part and risk evaluation part. It evaluates CO<sub>2</sub> migration in relation with fractures or faults of shallower aquifers and estimates impact of seepage in surface. The first generation tool is expected to complete at the end of this fiscal year. The tool is also expected to offer optimum level of quantified value of risk as decision-making basis, and support safety and risk management of CO<sub>2</sub> geological storage legislations.

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